UNDERWATER CONTROL OF MOBILE ROBOT

NATIONAL INSTITUTE OF TECHNOLOGY

ROURKELA

RAJ BABBAR KUMAR

Underwater control of mobile robot

A thesis submitted for the fulfillment and award of

Bachelor of Technology in Mechanical Engineering

by

Raj Babbar Kumar

111ME0305

Under the guidance of

Prof. Dayal Ramakrushna Parhi

Department of Mechanical Engineering

National Institute of Technology Rourkela

Odisha (India)-769008

Content

Declaration………………………………………………………………………………… (ii)

Certificate...……………………………………………………………………….…. (iii)

Acknowledgements…………………………………………………………..………... (iv)

Abstract……………………………………………………………………………..... (v)

Tables…………………………………………………………………………......... (vi)

Figures………………..…………………………………………………………...…. (vii)

Symbols……………………..……………………………………………………...... (ix)

1. Introduction…………………………………………………………….................. (2)

2. Literature ……………………………………………………………….................. (5)

3. Underwater robot Theory……….…………………………………………............ (11)

4. Designing and CAD modeling …….……………………………………………... (19)

5. Fuzzy Logic for control……….…………………………………………….......... (17)

6. Result and Discussion……………………………………………………….......... (29)

7. Conclusion………………………………………………………………….….. (32)

8. Reference……………………..……………………………………….……... (33)

Declaration

The work incorporated or fused or written in this proposal has not been, to the best of my insight, submitted to some other University or Institute for the grant of a degree or confirmation. Neither it has been copied from anywhere nor a part of anyone's thesis before.

(Raj Babbar Kumar)

Dated ……/…/…….

NATIONAL INSTITUTE OF TECHNOLOGY
ROURKELA -769008, ODISHA, INDIA.

Certificate

This is to certify that this is to ensure that the work in the proposal entitled "Underwater Control of mobile robot" by ***Mr. Raj Babbar Kumar*** *bearing Roll No.* ***111ME0305*** *submitted to National Institute of Technology, Rourkela for the recompense of Bachelor of Technology in Mechanical Engineering in the Department of Mechanical Engineering, is a record of a bonafide examination work completed by him in the Department of Mechanical Building under my watch and direction. The outcomes in the proposal have not been submitted for any degree or scholarly recompense somewhere else.*

Supervisor

Date: / /2015

Dr. D.R. Parhi

Professor

Department of Mechanical Engineering

National Institute of Technology Rourkela, Odisha-769008

Acknowledgement

I take this chance to express my significant appreciation and profound respects to my guide Prof. D.R. Parhi for his praiseworthy direction, observing and consistent support throughout this proposition. The gift, help and direction given by him time to time should convey me far in the adventure of life on which I am going to leave.

I express our true appreciation to Mr. Maheshwar Das, Ms. Shubhasri Kundu and to the Head of the Department, Mechanical Engineering, NIT Rourkela for giving me a chance to deal with this task and permitting me access to important workplaces in the department.

I am exceptionally obliged to all the teachers of the Department of Mechanical Engineering, NIT

Rourkela for imparting in me the essential information about the field that incredibly profited me while doing the undertaking and accomplishing my objective.

Additionally, I am profoundly obligated to the Department of Mechanical Engineering for showing me all that I know today.

Abstract

A self-sufficient submerged vehicle (AUV) is a robot which ventures submerged without obliging data from an administrator. AUVs constitute some piece of a bigger gathering of undersea frameworks known as unmanned submerged vehicles, an arrangement that incorporates non-self-governing remotely worked submerged vehicles (ROVs) – controlled and fueled from the surface by an administrator/pilot by means of an umbilical or utilizing remote control. In military applications AUVs are all the more regularly alluded to just as unmanned undersea vehicles (UUVs). Research on Autonomous Underwater Vehicle (AUV) has been expanding in the later a long time. They discover application in safeguard association for submerged mine identification and area observation, in oil/gas commercial ventures for recognition of spillage in the pipelines, in business reason for the vicinity of tiny life, centralization of different components, in trash field mapping and in numerous other marine commercial ventures. In this project I have developed and modeled an underwater robot. Also I have developed and used fuzzy logic for control of them.

Tables

Table 5.1: Various Parameters used for Obstacle distance…..……………………………..... (18)

Table 5.2: Various Parameters used for heading angle………………...…………………...... (18)

Table 5.3: Various Parameters used for elevation angle……………………………...….… (19)

Table 5.4: Parameters for the Motors used (forward and backward motion)……………….... (19)

Table 5.5: Parameters for the Motors used (for vertical motion)……………………………... (19)

Table 7.1: Specifications of robot……………………..……………………………………… (32)

List of figures

Figure 1.1 & 1.2: Examples of fabricated Underwater Vehicles………………………………. (3)

Figure 1.3: AUV 150…….…………………………………………………….…………….. (4)

Figure 1.4: Alister 100….……………………………………………………………………… (5)

Figure 3.1: The movements of an underwater robot are shown like Rolling, Pitching and Yaw.

………..……. ……………………………………………………………………..……... (9)

Figure 3.2: Tasks performed in an AUV……………………………..………..….……... (10)

Figure 3.3: Buoyancy force affecting the sinking and floating of an underwater object

……………………………………………………………………………...……….... (11)

Figure 3.4: Stability as a function of Centre of mass and center of buoyancy…..……..…….. (12)

Figure 4.1: The hull of the Robot…………………..…………………………………........ (13)

Figure 4.2: Frame for Stability……………………………………………………….…..... (14)

Figure 4.3: CAD design of Motor….……………………………………………….......... (15)

Figure 4.4: CAD model of the underwater vehicle made…………………………………….. (16)

Figure 5.1: Various inputs and outputs ………………..…………………………………….. (17)

Figure 5.2: Distance from the Front obstacle …………………………………………….... (20)

Figure 5.3: Distance from the Left obstacle …………….……………………………………. (20)

Figure 5.4: Distance from the Left obstacle …………………………………………………...... (21)

Figure 5.5: Figure representing the Heading Angle-Azimuth angle Graph………..…………. (21)

Figure 5.6: Figure representing the Heading angle – Elevation Angle graph……..………….. (22)

Figure 5.7: Figure representing the Target Angle – Azimuth angle graph…….….………... (22)

Figure 5.8: Figure representing the Target Angle- Elevation Angle graph……….………….. (23)

Figure 5.9: Output variable representing the Motor 1 Graph……………………………..... (23)

Figure 5.10: Output variable representing the Motor 2 Graph……………………………..…. (24)

Figure 5.11: Output variable representing the Motor 3 Graph……………………………... (24)

Figure 5.12: Output variable representing the Motor 4 Graph…………………………....... (25)

Figure 6.1: The CAD model of the underwater robot made in the lab……….………......... (29)

Figure 6.2: Defuzzification values …………………………………..……………..…..… (31)

List of symbols

x_b - Surge

y_b - Sway

z_b - Heave

φ_b - Roll

ψ_b - Yaw

θ_b – Pitch

O_W- Origin of world frame

O_B- Origin of body frame

LOD: Left Obstacle distance

ROD: Right Obstacle distance

FOD: Front obstacle distance

HA- Heading angle

TA-Target angle

AA- Azimuth angle

EA-Elevation angle

1. INTRODUCTION

Submerged vehicle are fundamentally are of three sorts: Remotely Operated Vehicle (RUV), Autonomous Underwater Vehicle (AUV) and Unmanned Underwater Vehicle (UUV). AUV is a robot outfitted with suitable sensors and actuators which empower it to explore in ocean environment. The main AUV was created by Stan Murphy and Bob Francois at the Applied Physics Laboratory at the University of Washington. From that point forward research on AUV as shown in Fig. 1.1 has been expanding. MAYA AUV by NIO was the first indigenously created AUV in India. Essentially control of an AUV alludes to the capacity of the vehicle to explore in ocean environment with no human intercession. AUV as shown in Fig. 1.2 is exceptionally helpful in number of intriguing applications, for example, submerged mine recognition, area observation, oil/gas businesses for examination of in the pipelines and other marine related businesses.

Figure 1.1 Some example of commercial AUV

It is additionally helpful in environment checking for the vicinity of infinitesimal life, convergence of different components and garbage field mapping. AUV like AUV150 as shown in Fig. 1.3 by CSIR-CMERI, India, TALISMAN by BAE frameworks and ALISTER 100 as shown in Fig. 1.4 by eca Robotics, Starfish 2 USA naval force by Blue star discover applications in protection and other military application. MAYA AUV by NIO, India, and MARUM AUV by University of BREMEN, Sea Duane 2 from Flinders University Adelaide Australia and SeaCAT AUV by RUVSA are utilized for marine exploration/environment studies.

Figure 1.2 Examples of fabricated Underwater Vehicles

Some AUV are likewise utilized in air crash examination like AUV Abyss by GEOMAR - Helmholtz Centrum . In most of the application it is obliged that it ought to take after a sought way like checking, reconnaissance or pipeline of a sought area. Nonetheless it’s exceptionally difficult as AUV element being extremely perplexing, time shifting, non direct and unverifiable.

Control of AUV is troublesome in view of the way that is it is an under actuated framework and its progress is affected by sea streams and hydrodynamic impacts.

Figure 1.3 AUV 150

The next page shows the various underwater vehicles like AUV150 made by CSIR CMERI, from India and the ALISTER 100 is a robot which is made by the eca Robotics. These are shown Fig. 1.3 and 1.4.

Figure 1.4 Alister 100

Equipped for directing port leeway missions, the GPD will convey the frameworks for supporting missions, for example, a seabed study or surveillance, and additionally propelled operations incorporating in exceptionally shallow water, or for channel attack.

The AUV, which can be worked by two mariners sitting on a dock or installed an inflatable watercraft, is fitted with cutting edge frameworks and sensors to give an exact route capacity to the naval force to recognize potential submerged mines.

Notwithstanding supporting minehunting operations, even in tight ocean territories, for example, channels or gulfs, the independent submerged vehicle can be utilized to trade of data with other battle frameworks utilized for mine fighting.

The vehicle is likewise outfitted with a Klein-sort sonar, intended to work on diverse frequencies, keeping in mind the end goal to bolster either detecting range or picture definition, contingent upon operational circumstances.

2. LITERATURE REVIEW

With a specific end goal to accomplish the way taking after control of an AUV the lapse between the way parameters and the AUV position and introduction need to be lessened to zero. For this the control inputs to the AUV are thrusters' power and the introduction of the rudders, stern and bows point. As the complete progress is nonlinear six DOF mathematical statement of movement with coupled and non-direct terms including included mass, hydrodynamic damping and outer unsettling influences.

So its turns out to be extremely hard to accomplish the exact way taking after by utilizing the ordinary controllers input linearization have been executed for AUV way taking after. In sliding mode control plan [1], the methodology is taking into account information yield motions regarding jump plane profundity estimation and summons signals. A non-straight increase planning controller is likewise being proposed for control of an AUV [2] where the control is done in vertical plane. In another configuration the motion of AUV is composed in strict-criticism structure and afterward a stable versatile nonlinear controller for plunge control of an AUV is being composed by utilizing Lyapunov based Back stepping strategy [3].

A neural system versatile controller has been moreover proposed for profundity plane control of an AUV [4]. In the fluffy sliding-mode controller configuration approach [5] AUV's pitch movement is viewed as went hand in hand with the aggravation of sea ebb and flow. Straight framework disparity preparing (LMI) system is being proposed [6] for the configuration of a powerful controller for plunge plane control of an AUV whereby the aggravations and control limitation is additionally being considered. A circuitous powerful controller is being outlined whereby the vulnerabilities are being handles by forming the vulnerability limits into the expense capacity and changing over the hearty control issue into its comparable ideal control issue [7].

A T–S fluffy model – based controller [8] have been likewise composed where the AUV in the vicinity of parametric vulnerabilities are spoken to by T–S fluffy model and after that in order to accomplish power of the profundity control an adequate condition is being inferred by utilizing a Lyapunov work as direct grid disparities (LMIs).The control of AUVs in the jump plane utilizing the state-subordinate riccati mathematical statement system is likewise being proposed [9]. Versatile control have been likewise proposed [12-15].In such approach the dynamic criticism circle is utilized for producing the assessments of obscure controller parameters for vulnerabilities.

3. THEORY OF UNDERWATER VEHICLE

The various motions for example: Surge sway heave roll pitch and yaw are being shown by the various equations. The various notation x_b , $y_b, z_b, \varphi_b, \psi_b, \theta_b$, have been named as Surge, Sway, Heave, Roll, Pitch and Yaw motions. The two origins, i.e. the World-frame and Body-frame have been defined by the notations O_W and O_B.

$$x = [\,Surge \quad Sway \quad heave \;\; roll \quad yaw \quad pitch\,]$$

Or

$$x = [\,x_b \;\; y_b z_b \varphi_b \psi_b \theta_b] \qquad \text{———————} \qquad (1)$$

And

$$\eta = [\,x \quad y \quad z \quad \varphi \quad \psi \;\; \theta]^{\mathrm{T}} \qquad \text{———————} \qquad (2)$$

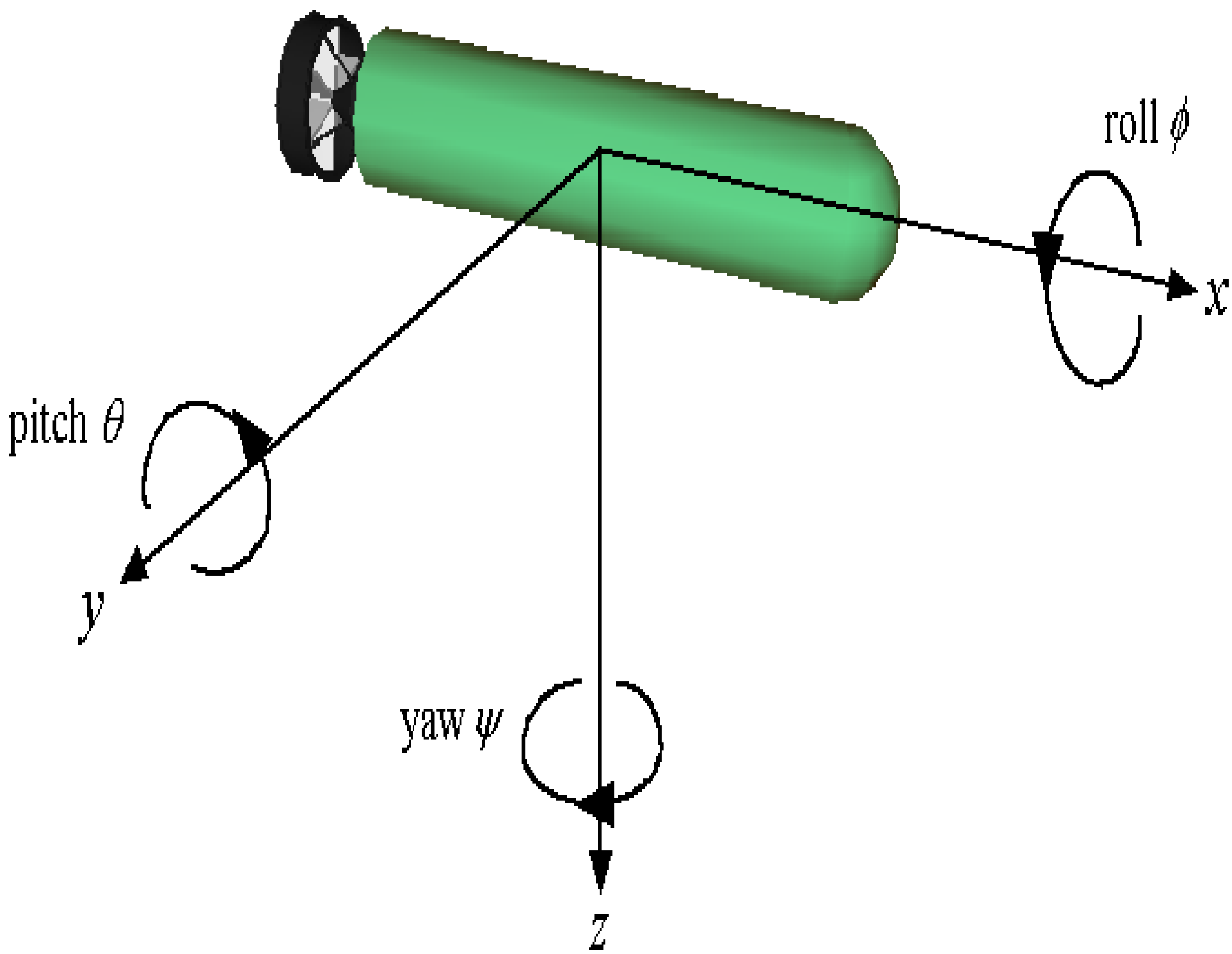

Figure 3.1: The movements of an underwater robot are shown like Rolling, Pitching and Yaw.

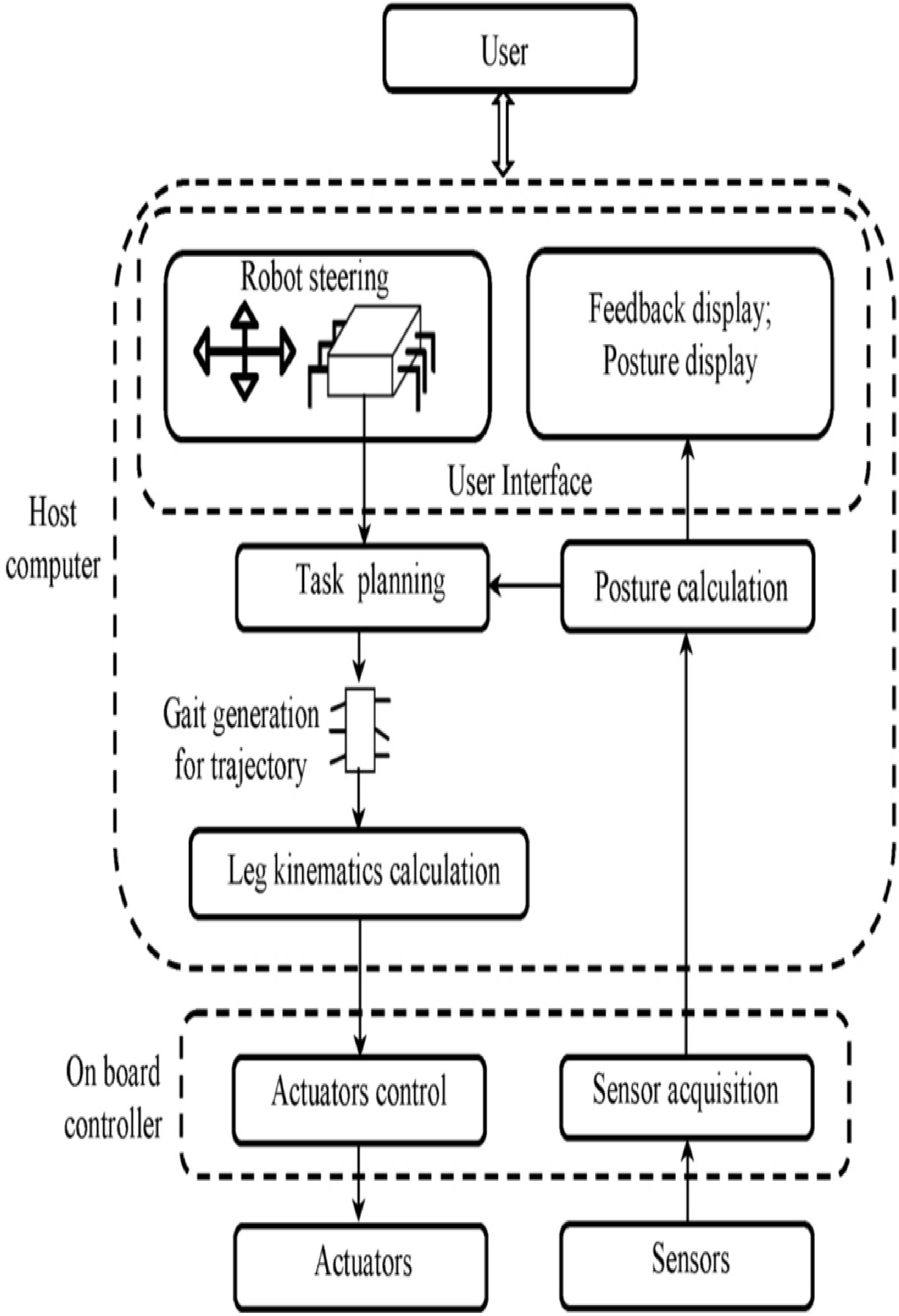

Figure 3.2: Tasks performed in an AUV.

3.2 Various Factors which affect the motion of an Underwater Robot

A. Buoyancy

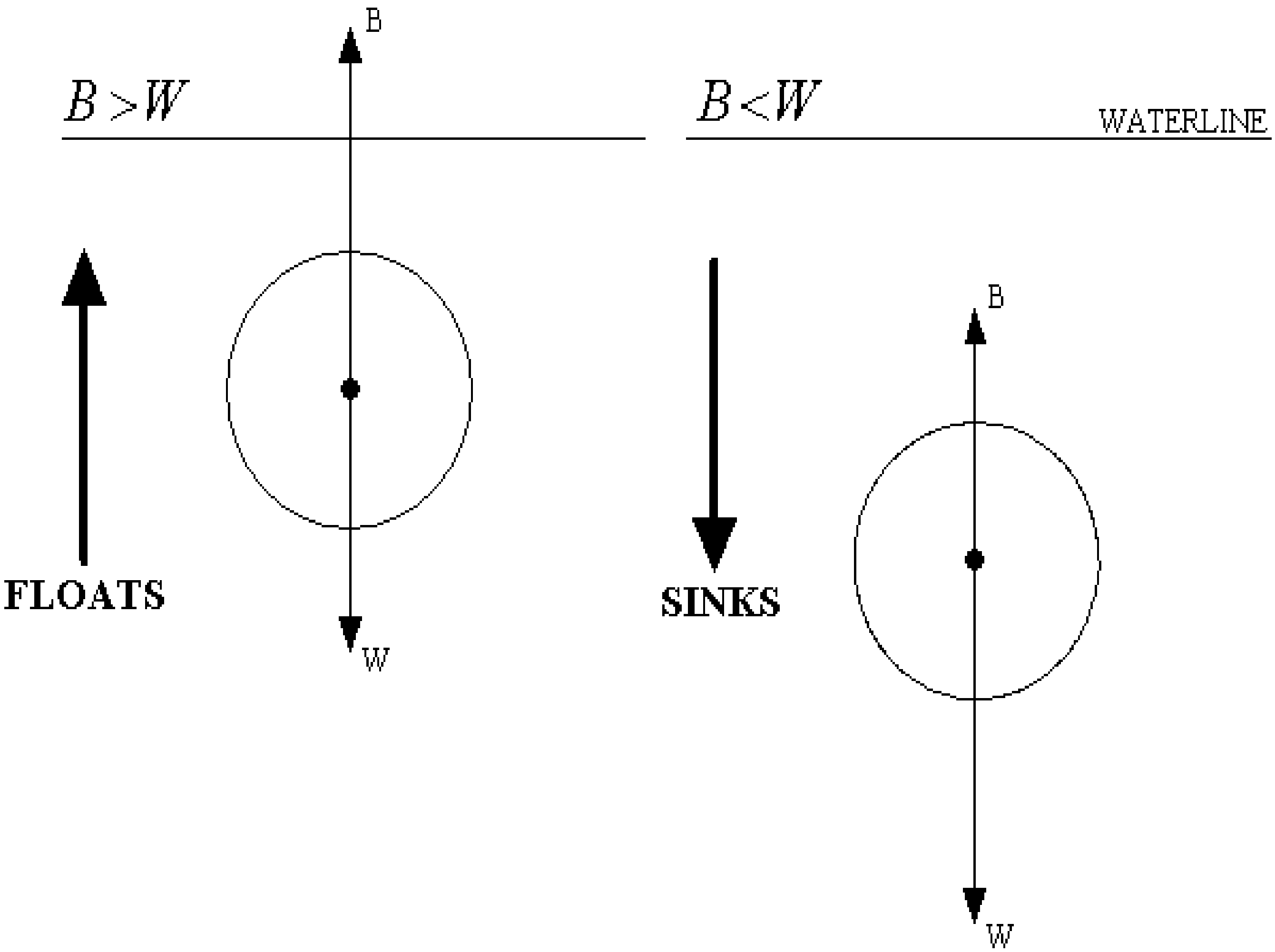

Figure 3.3: Buoyancy force affecting the sinking and floating of an underwater object

B. Stability

Stability of an underwater vehicle depend on the position of centre of mass and centre of buoyancy.

The effects of these are shown in Fig. 3.4.

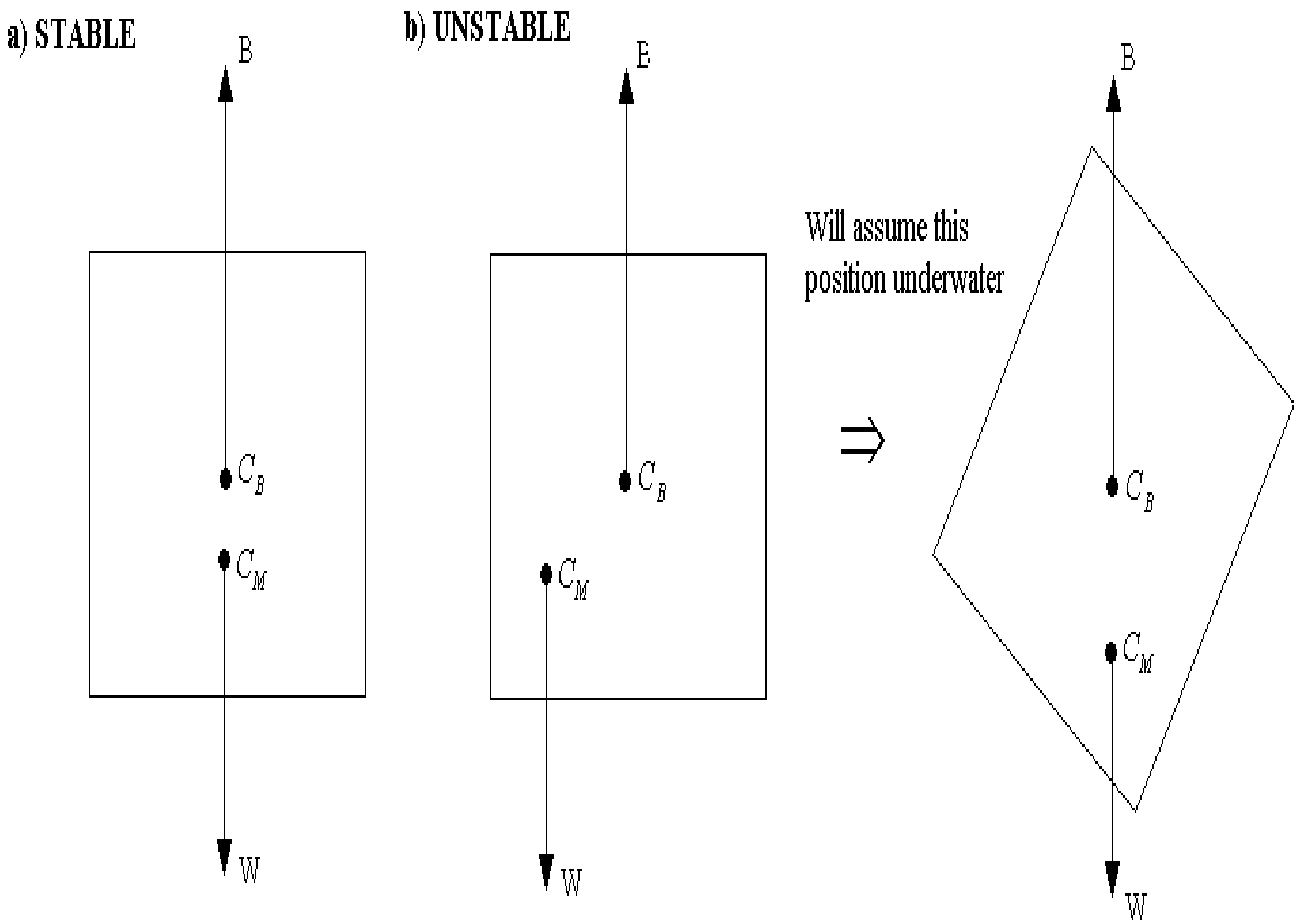

Figure 3.4: Stability as a function of Centre of mass and center of buoyancy

4. DESIGNING AND CAD MODELLING

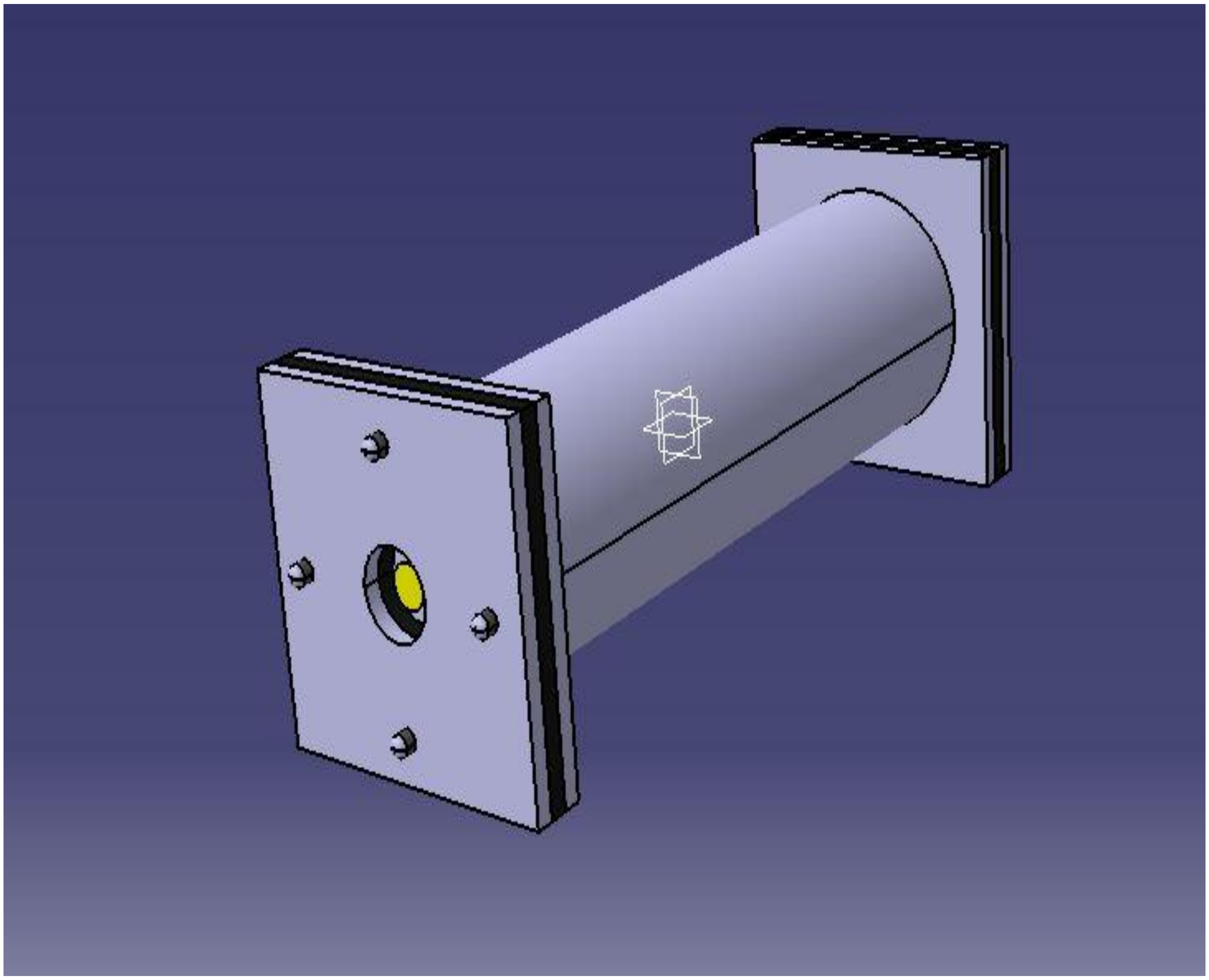

Figure 4.1: The hull of the Robot

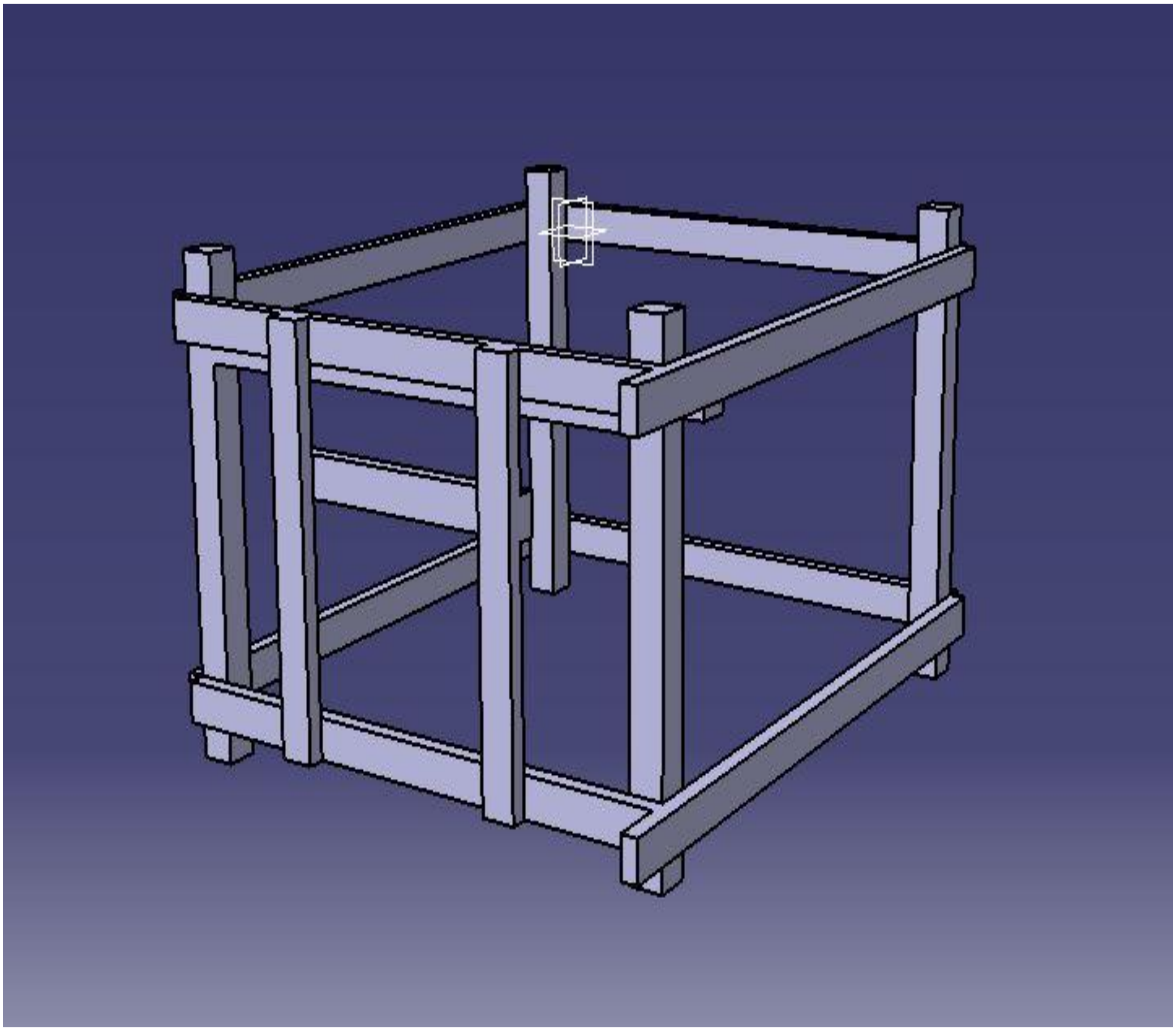

Figure 4.2: Frame for Stability

The above frame provides robustness and stability and also enough inertia to the robot against hydrodynamic forces and unwanted added mass fluctuations and instability.

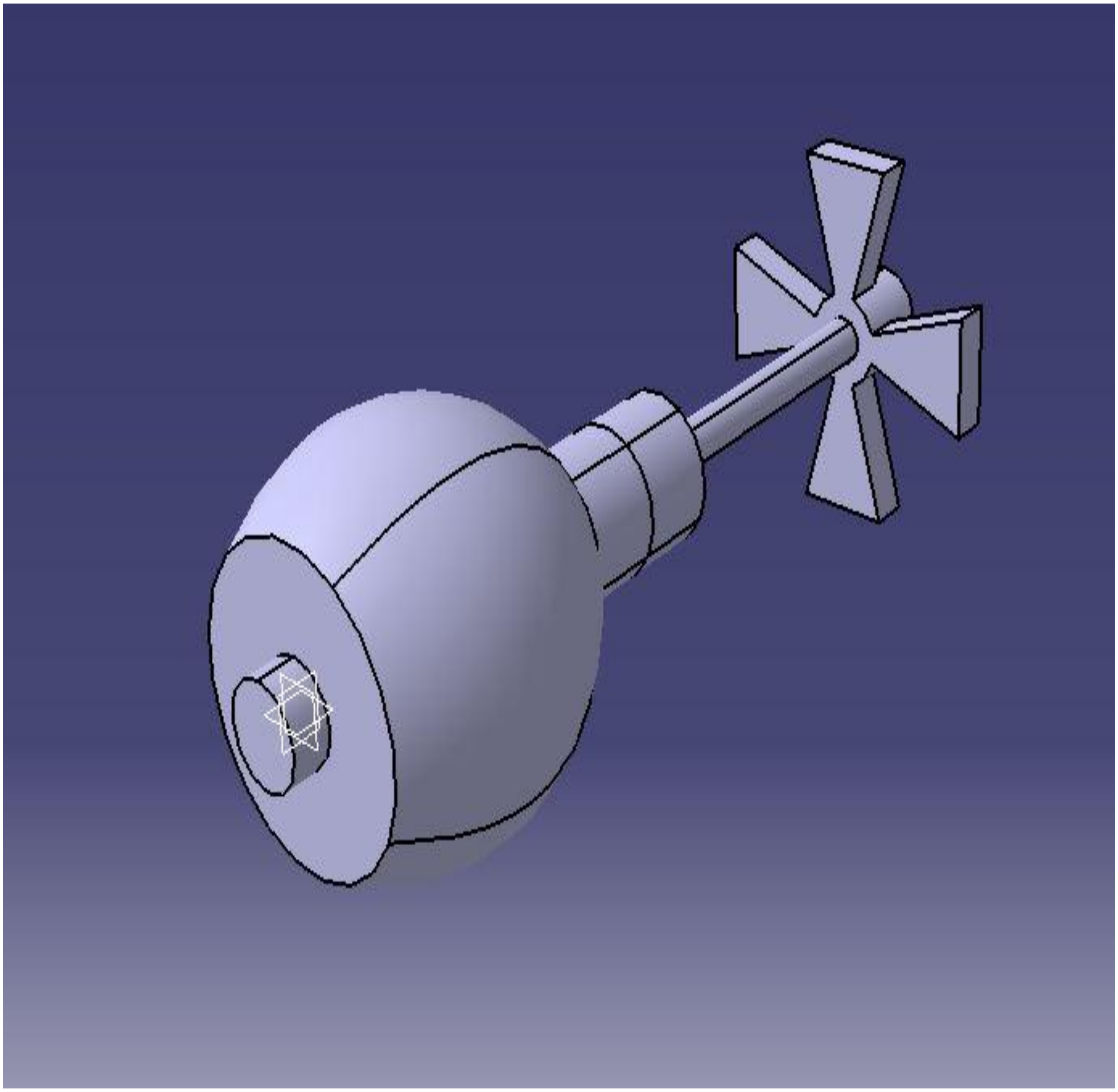

Figure 4.3: CAD design of Motor

The motor has been made using various things and has been made exclusively in the laboratory.

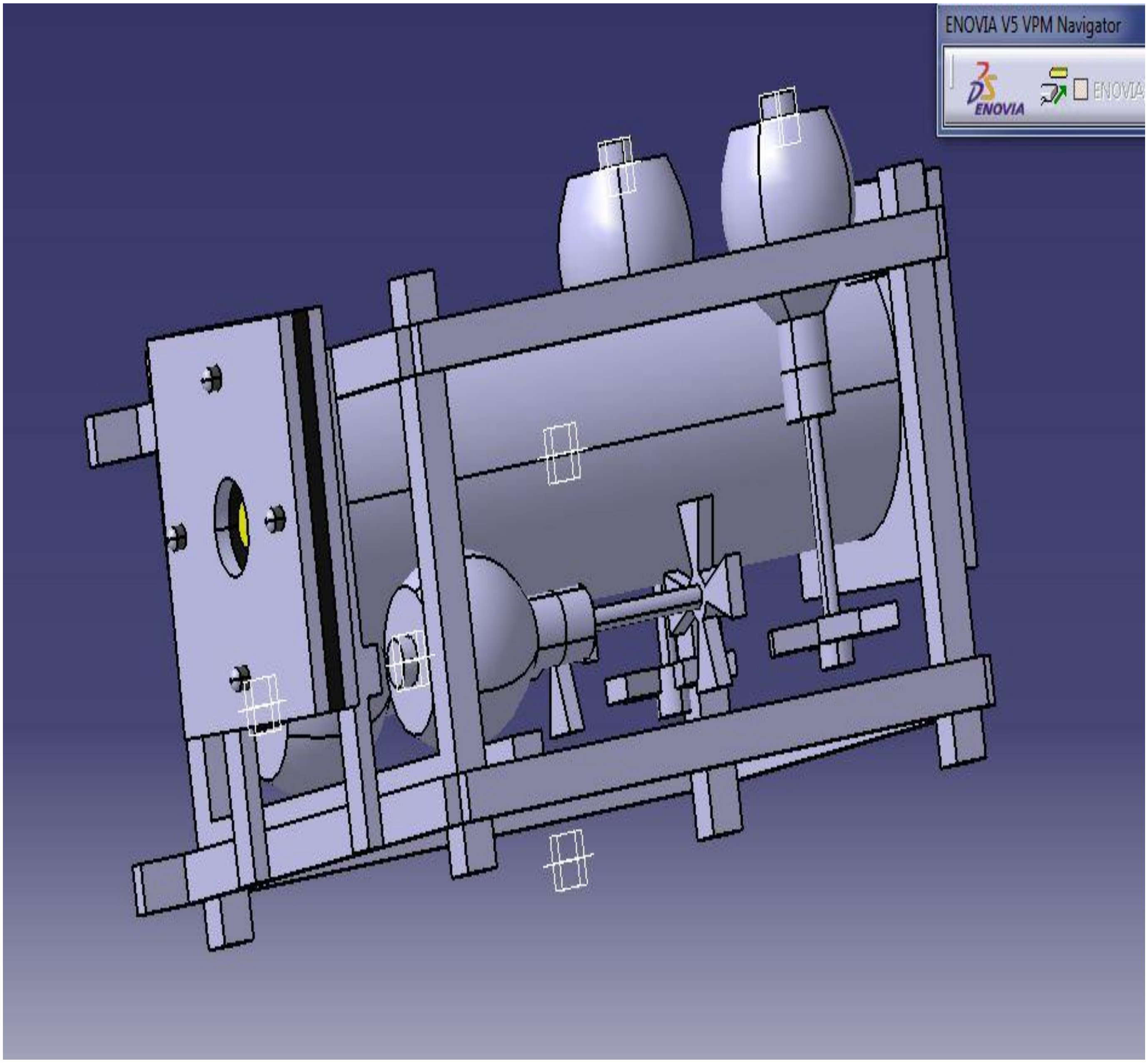

Figure 4.4: CAD model of the underwater vehicle made

5. FUZZY LOGIC FOR CONTROL

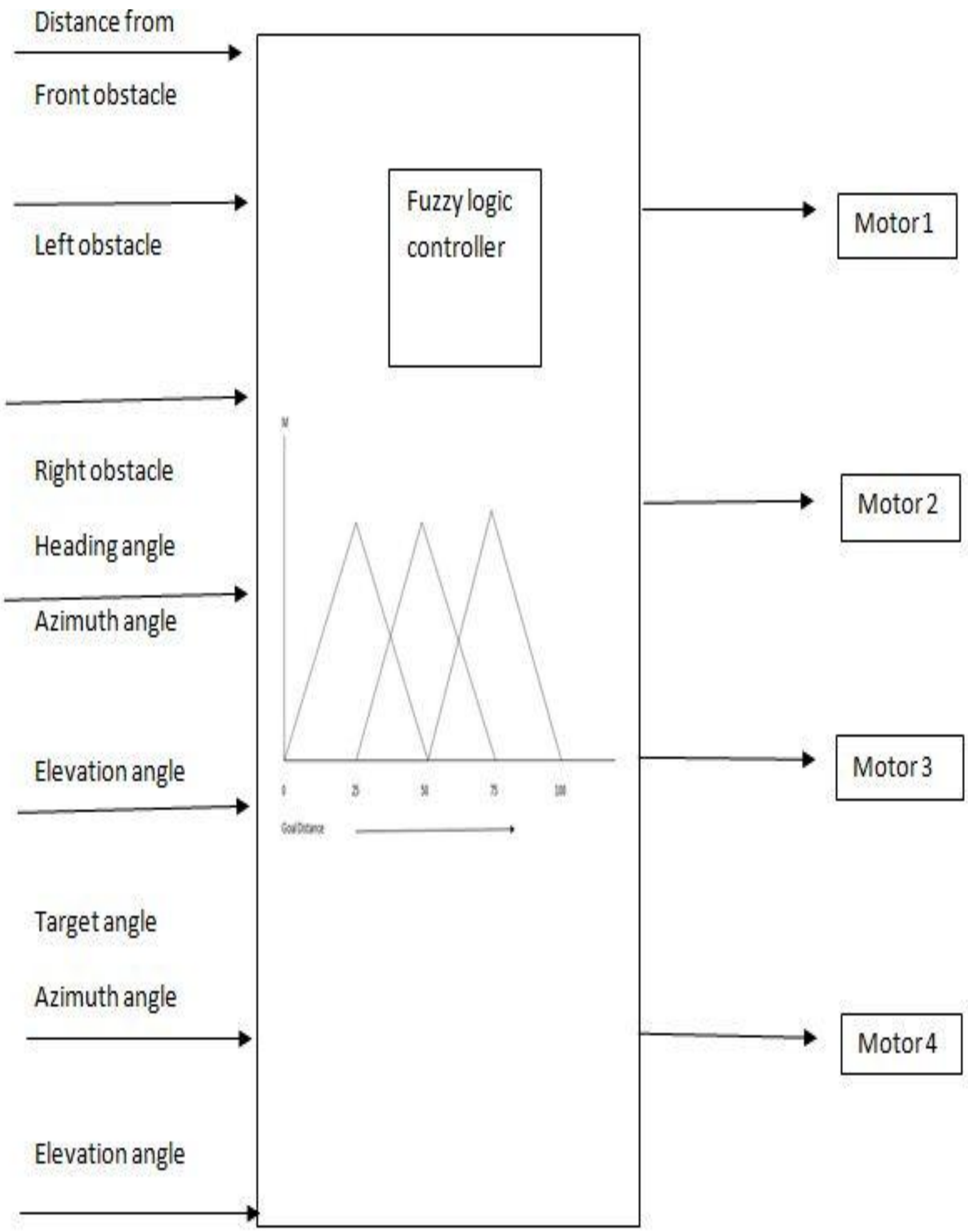

Figure 5.1: Various inputs and outputs have been shown

Various Parameters of fuzzy membership functions:

Table 5.1: Parameters for Obstacle distance

Variables(M.F.)	Parameters in metres			
Near (Triangular M.F.)		0	25	50
Medium Triangular M.F.)		25	50	75
Far (Triangular M.F.)		50	75	100

Various Parameters of fuzzy membership functions:

To show the fluffy rationale control capabilities of MATLAB we will recreate the sample that was already worked through. We will utilize the same information and yield enrollment capacities; A1, A2, B1 and B2. To start, we will characterize a Simulink model that will be utilized to run the reenactment.

Table 5.2: Parameters for azimuth angle

Variables(Membership functions)	Parameters in degrees		
Negative(Triangular)	-180	-90	0
Zero(Triangular)	-90	0	90
Positive(Triangular)	0	90	180

Table 5.3: Parameters of elevation angle

Variables(Membership functions)	Parameters in degrees		
Negative(Triangular)	-60	-30	0
Zero(Triangular)	-30	0	30
Positive(Triangular)	0	30	60

Table 5.4: Parameters of motors (forward and backward motion)

VARIABLES(MEMBERSHIP FUNCTIONS)	PARAMETERS OF VELOCITY		
SLOW(TRIANGULAR)	0	0.3925	0.785
MEDIUM(TRIANGULAR)	0.3925	0.785	1.1775
FAST(TRIANGULAR)	0.785	1.1775	1.57

Table 5.5: Parameters for motors (for vertical motion)

Variables(membership functions)	Parameters of velocity		
Slow(triangular)	0	0.1425	0.285
Medium(triangular)	0.1425	0.285	0.4275
Fast(triangular)	0.285	0.4275	0.57

Open MATLAB and Simulink and make another document. Include an incline information, Scope, and Fuzzy Logic Controller with Rule viewer to the document as indicated. The Fuzzy Logic Controller with Rule viewer piece can be found in the fluffy rationale tool compartment or by writing the name in the pursuit box of the Library Browser.

Graphs of various Fuzzy membership functions corresponding various parameters

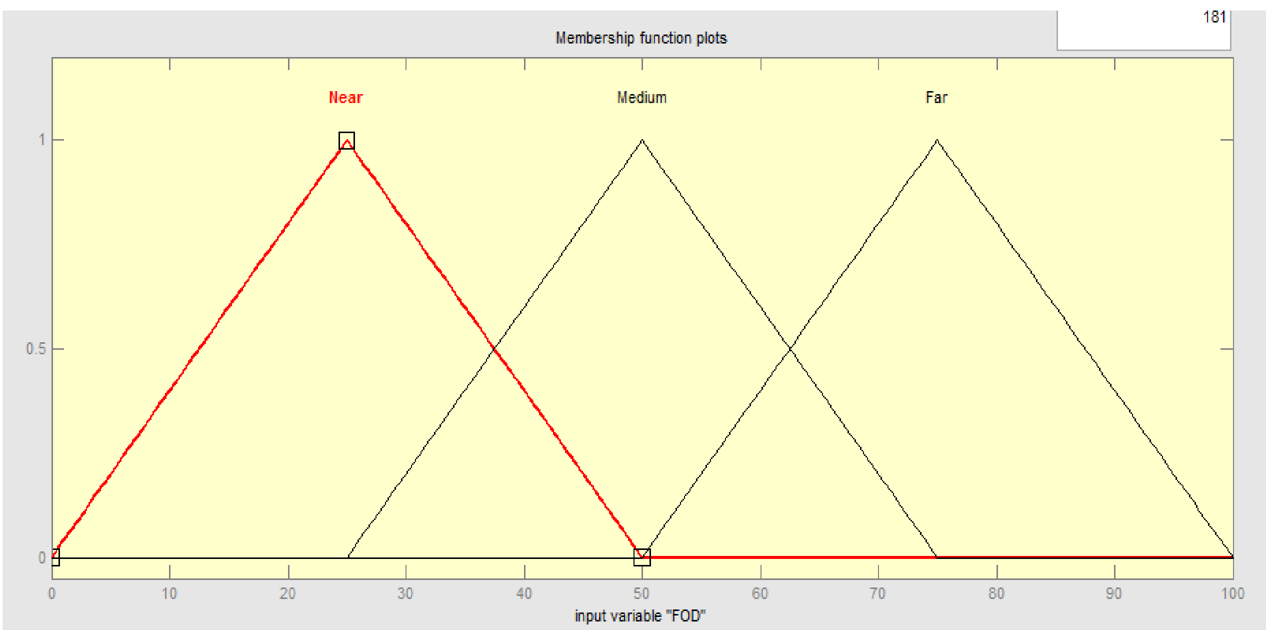

Figure 5.2: Distance from the Front obstacle

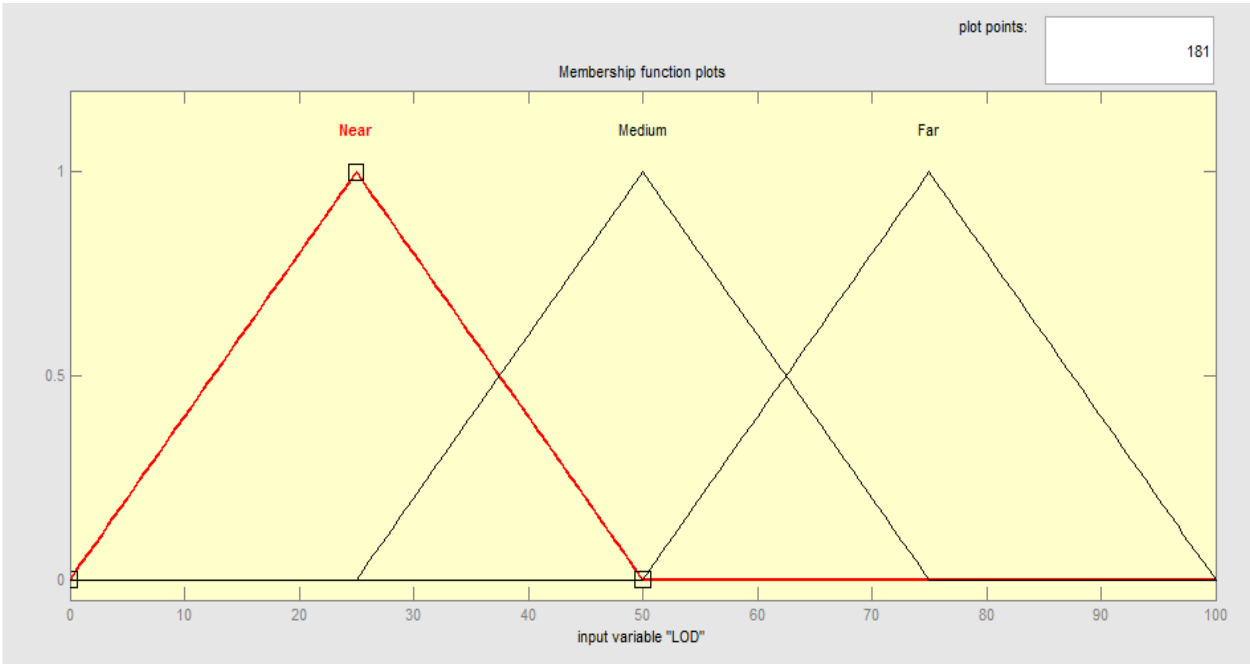

Figure 5.3: Distance from the Left obstacle

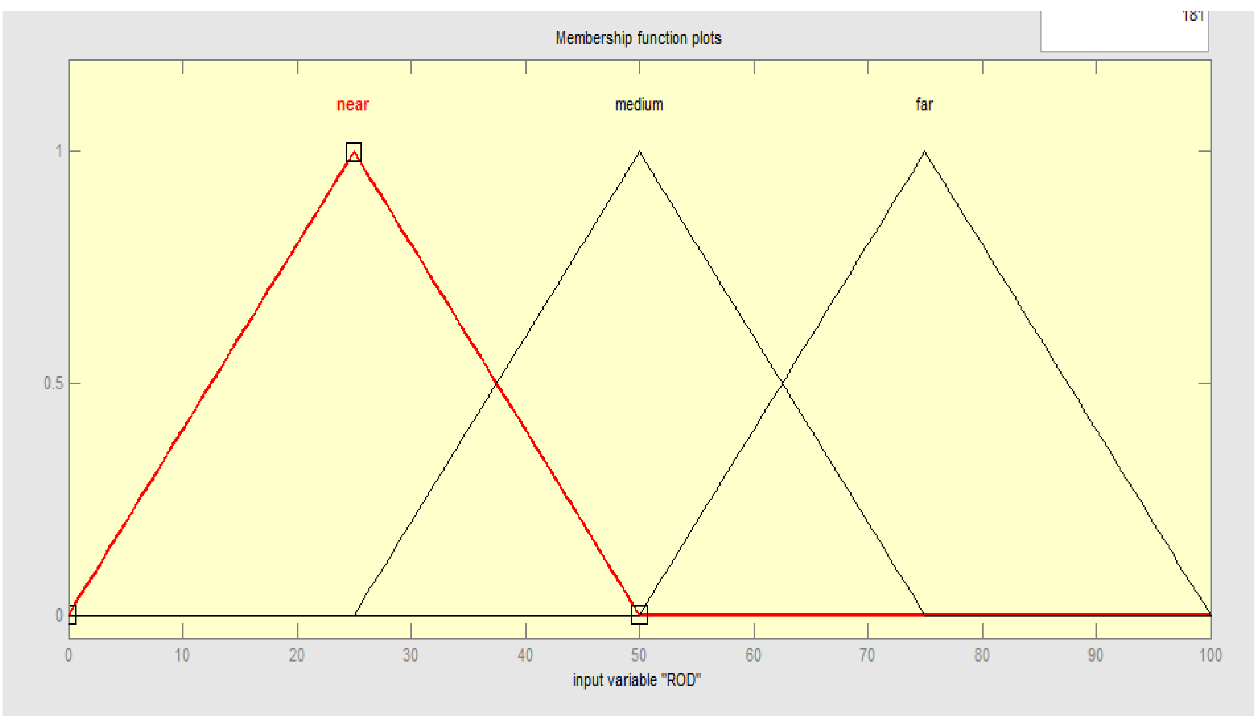

Figure 5.4: Distance from the Right obstacle

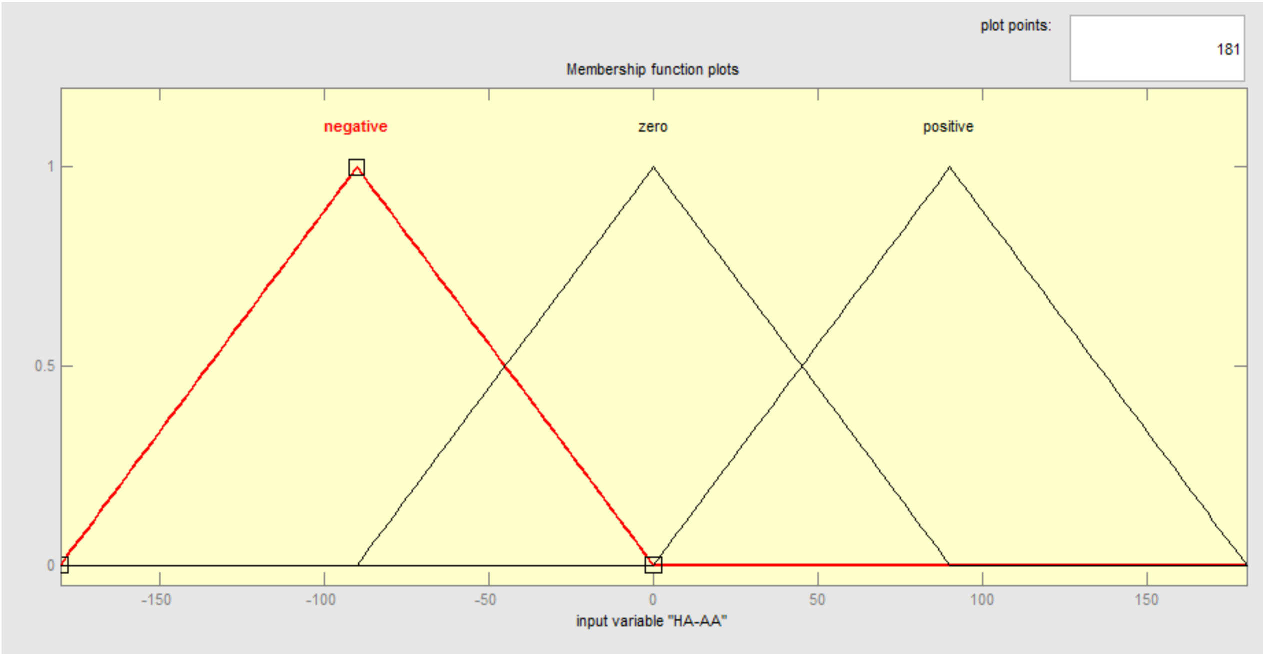

Figure 5.5: Figure representing the Heading Angle-Azimuth angle

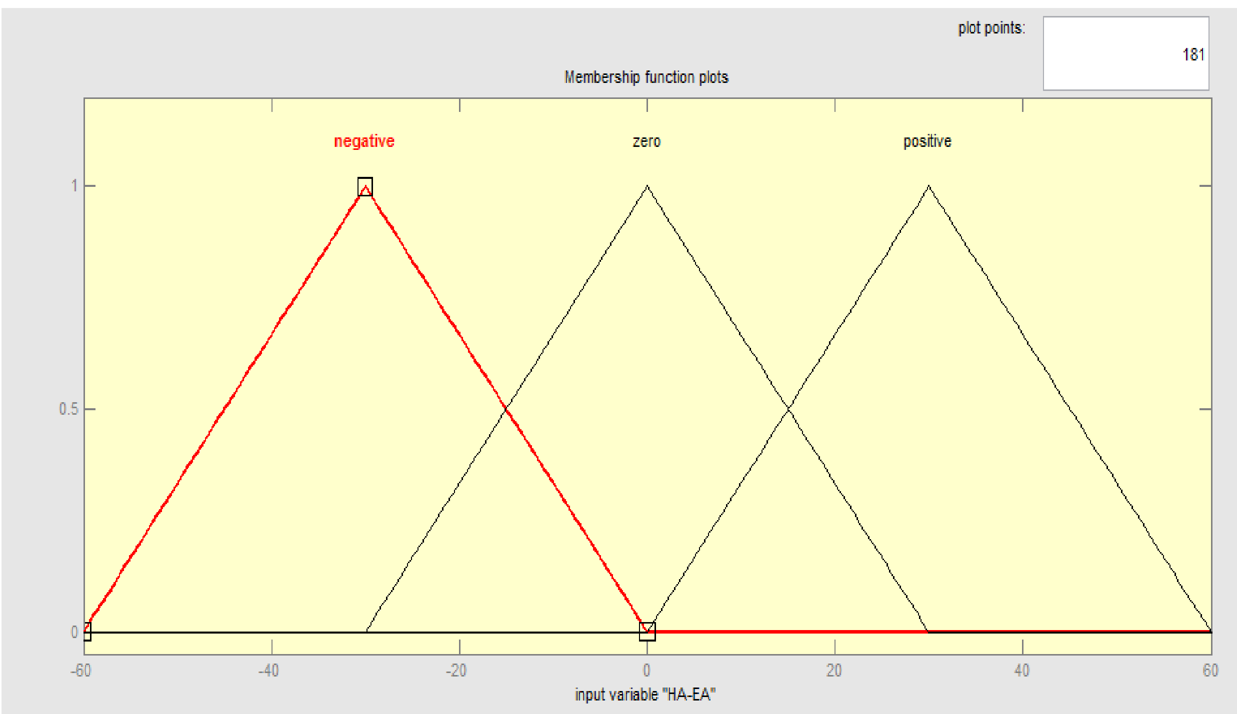

Figure 5.6: Figure representing the Heading angle – Elevation Angle graph

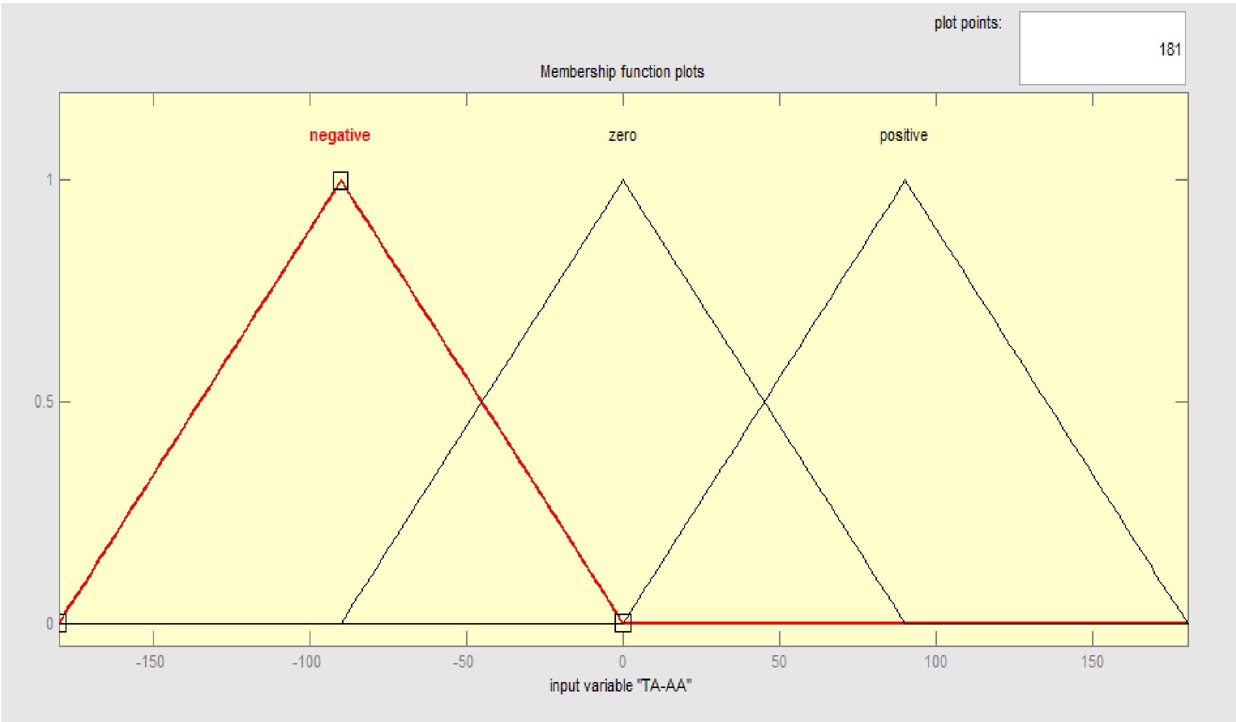

Figure 5.7: Figure representing the Target Angle – Azimuth angle graph

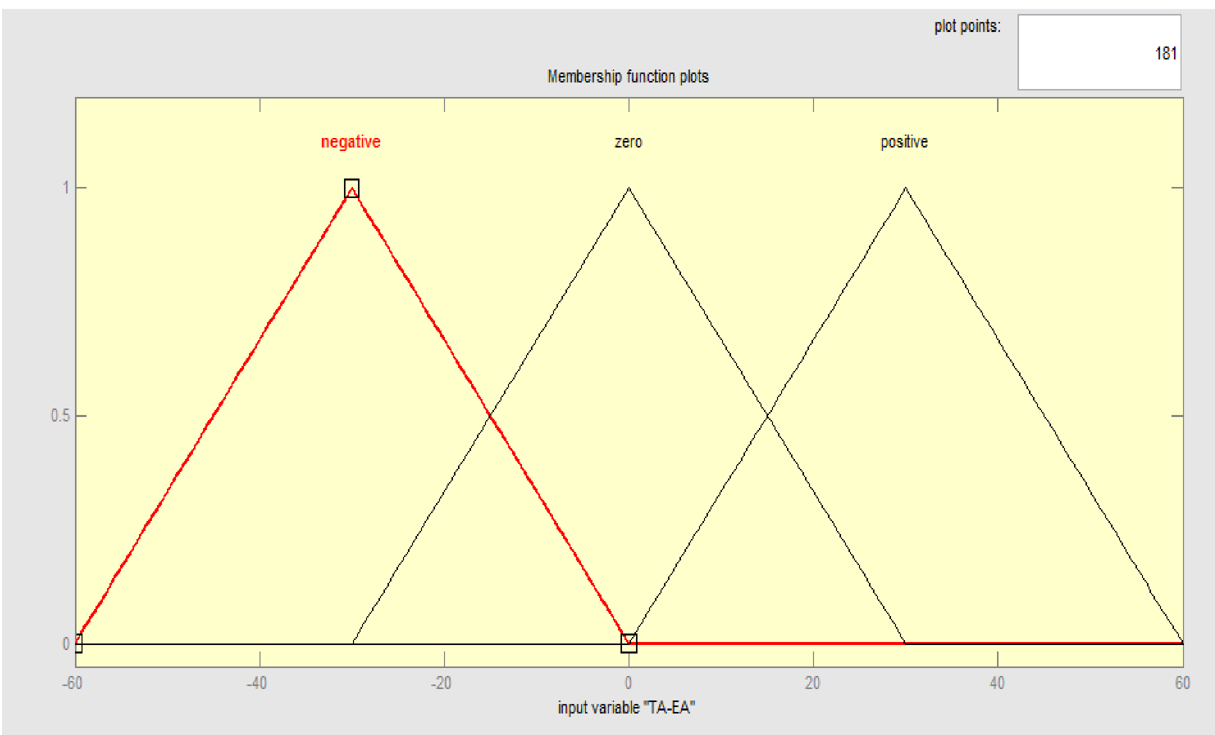

Figure 5.8: Figure representing the Target Angle- Elevation Angle graph

Output Membership function

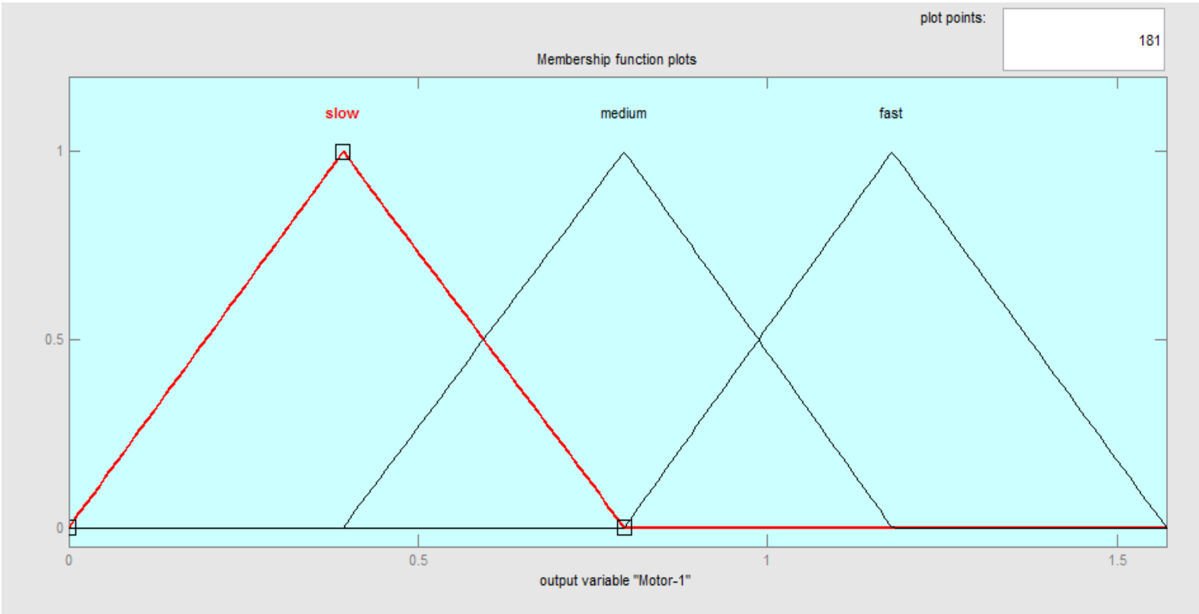

Figure 5.9: Output variable representing the Motor 1

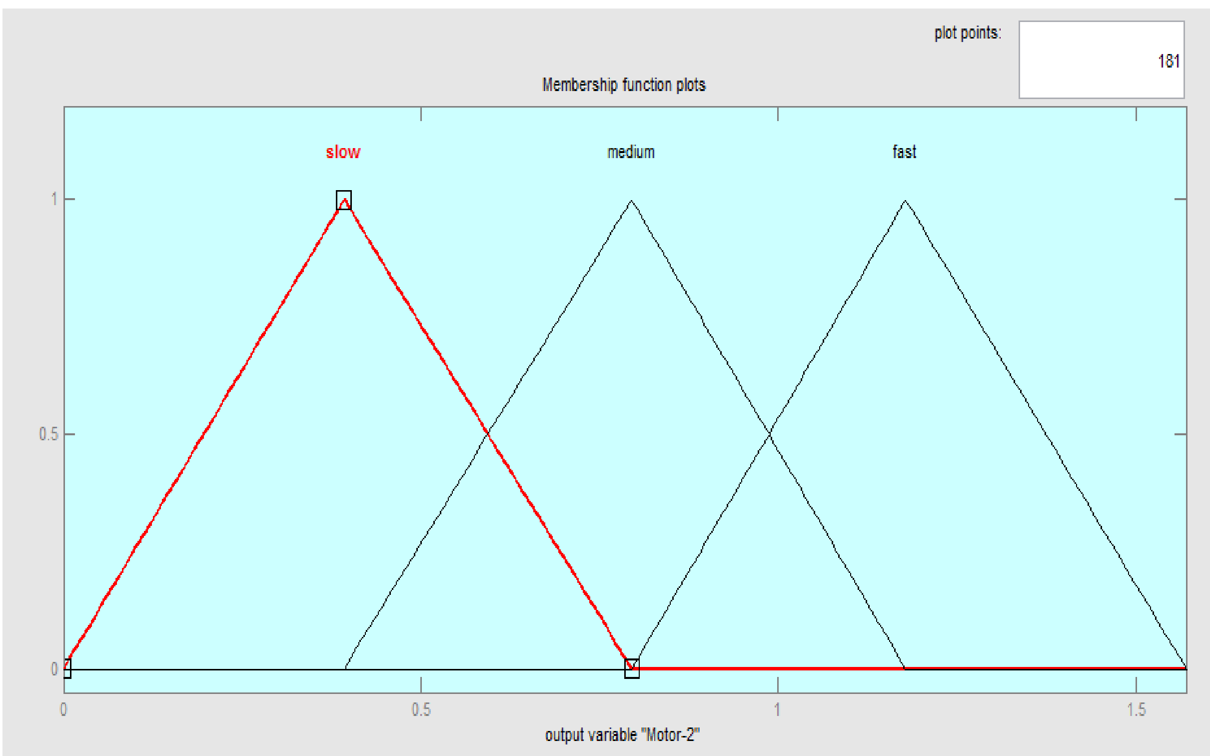

Figure 5.10: Output variable representing the Motor 2

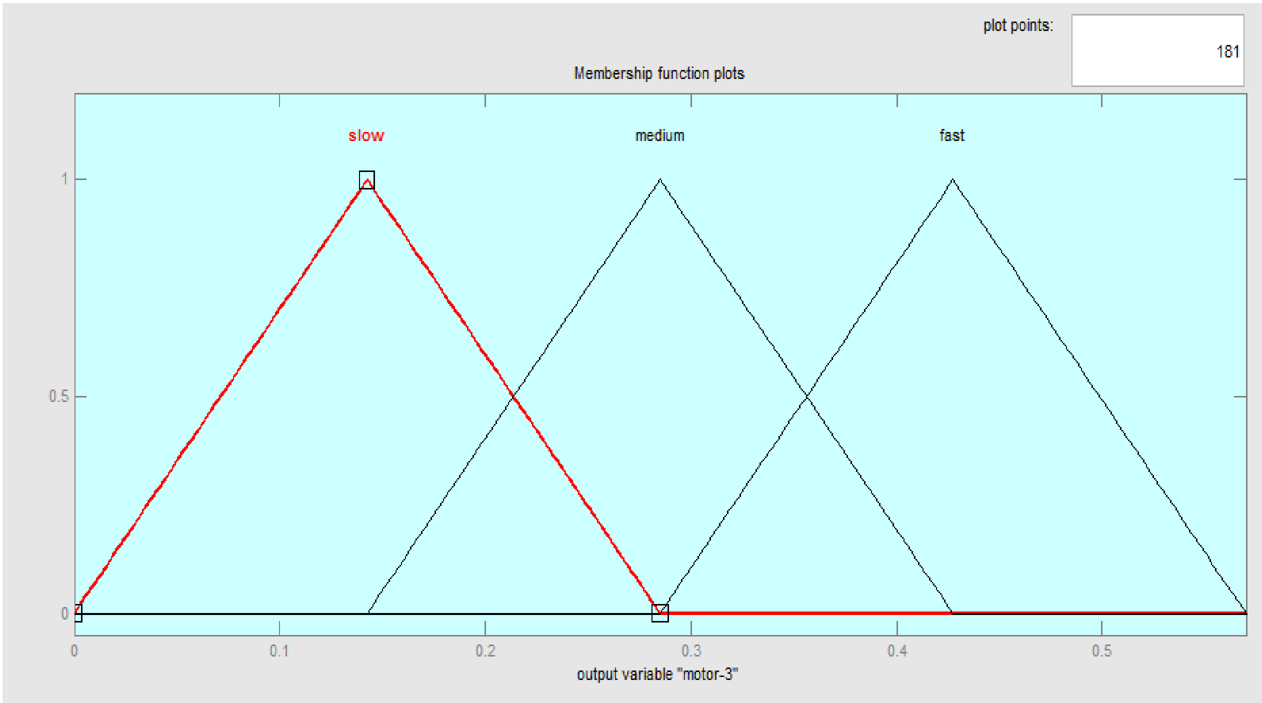

Figure 5.11: Output variable representing the Motor 3

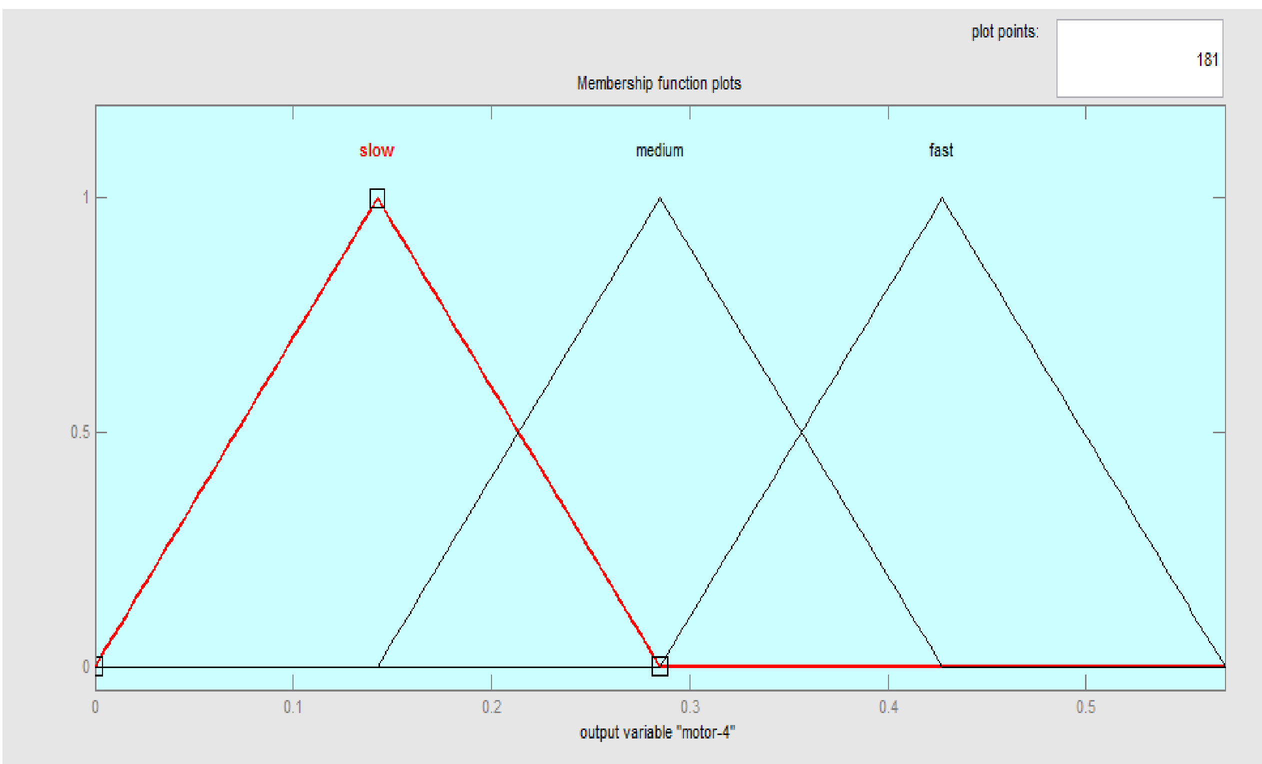

Figure 5.12: Output variable representing the Motor 4

There have been various rules made for fuzzy logic controller:-

1. if front obstacle distance is near, left obstacle distance is near and right obstacle distance is far and heading angle-azimuth angle is positive and heading angle-elevation angle is zero and target angle-azimuth angle is zero and target angle-elevation angle is zero then Motor 1 is fast and Motor-2 is medium.

2. If front obstacle distance is near, left obstacle distance is medium and right obstacle distance is far and heading angle-azimuth angle is positive and heading angle-elevation angle is zero and target angle-azimuth angle is zero target angle-elevation angle is zero then motor 1 is fast and Motor-2 is slow

3. If front obstacle distance is near, left obstacle distance is medium and right obstacle distance is far and heading angle-azimuth angle is zero and heading angle-elevation angle is zero and target angle-azimuth angle is zero target angle-elevation angle is zero then Motor 1 is fast and Motor-2 is slow

4. If front obstacle distance is near, left obstacle distance is near and right obstacle distance is medium and heading angle-azimuth angle is positive and heading angle-elevation angle is zero and target angle-azimuth angle is zero target angle-elevation angle is zero then Motor 1 is fast and Motor-2 is slow Motor.

5. If front obstacle distance is near, left obstacle distance is near and right obstacle distance is medium and heading angle-azimuth angle is positive and heading angle-elevation angle is negative and target angle-azimuth angle is positive target angle-elevation angle is zero then Motor 1 is fast and Motor-2 is slow Motor 4 is fast.

6. If front obstacle distance is near, left obstacle distance is medium and right obstacle distance is far and heading angle-azimuth angle is positive and heading angle-elevation angle is negative and target angle-azimuth angle is positive target angle-elevation angle is zero then motor 1 is fast and motor-2 is slow motor 4 is medium.

7. If front obstacle distance is medium, left obstacle distance is medium and right obstacle distance is far and heading angle-azimuth angle is positive and heading angle-elevation angle is negative and target angle-azimuth angle is positive target angle-elevation angle is zero then motor 1 is medium and motor-2 is slow motor 4 is medium.

8. If front obstacle distance is far, left obstacle distance is medium and rod is far and heading angle-azimuth angle is positive and heading angle-elevation angle is negative and target angle-azimuth angle is zero target angle-elevation angle is zero then Motor 1 is medium and Motor-2 is slow Motor 4 is fast.

9. If front obstacle distance is far, left obstacle distance is near and right obstacle distance is far and heading angle-azimuth angle is positive and heading angle-elevation angle is negative and target angle-azimuth angle is zero target angle-elevation angle is zero then Motor 1 is medium and Motor-2 is slow Motor 4 is fast.

10. If front obstacle distance is far, left obstacle distance is near and rod is medium and heading angle-azimuth angle is positive and heading angle-elevation angle is negative and target angle-azimuth angle is zero target angle-elevation angle is zero then Motor 1 is medium and Motor-2 is slow Motor 4 is medium.

11. If front obstacle distance is far, left obstacle distance is far and right obstacle distance is medium and heading angle-azimuth angle is positive and heading angle-elevation angle is

negative and target angle-azimuth angle is zero target angle-elevation angle is zero then Motor 1 is medium and Motor-2 is fast Motor 4 is medium.

12. If front obstacle distance is far, Left obstacle distance is far and Right Obstacle distance is near and heading angle-azimuth angle is positive and heading angle-elevation angle is negative and target angle-azimuth angle is zero target angle-elevation angle is zero then motor 1 is slow and motor-2 is fast Motor 4 is medium.

13. If front obstacle distance is near, left obstacle distance is medium and right obstacle distance is far and heading angle-azimuth angle is positive and heading angle-elevation angle is negative and target angle-azimuth angle is positive target angle-elevation angle is zero then motor 1 is fast and motor-2 is slow motor 4 is medium.

14. If front obstacle distance is medium, left obstacle distance is medium and right obstacle distance is near and heading angle-azimuth angle is positive and heading angle-elevation angle is negative and target angle-azimuth angle is zero target angle-elevation angle is zero then Motor 1 is medium and Motor-2 is fast Motor 4 is medium.

15. If front obstacle distance is medium, Left obstacle distance is far and Right obstacle distance is near and heading angle-azimuth angle is positive and heading angle-elevation angle is negative and target angle-azimuth angle is zero target angle-elevation angle is zero then motor 1 is medium and motor-2 is fast Motor 4 is medium.

16. If front obstacle distance is medium, left obstacle distance is far and right obstacle distance is near and heading angle-azimuth angle is positive and heading angle-elevation angle is positive and target angle-azimuth angle is zero target angle-elevation angle is zero then Motor 1 is medium and Motor-2 is fast Motor 3 is fast.

6. RESULT AND DISCUSSION

Hence an underwater robot is made with 2 motors for forward motion, acrylic pads and rubber sheets. PVC hull has been used.

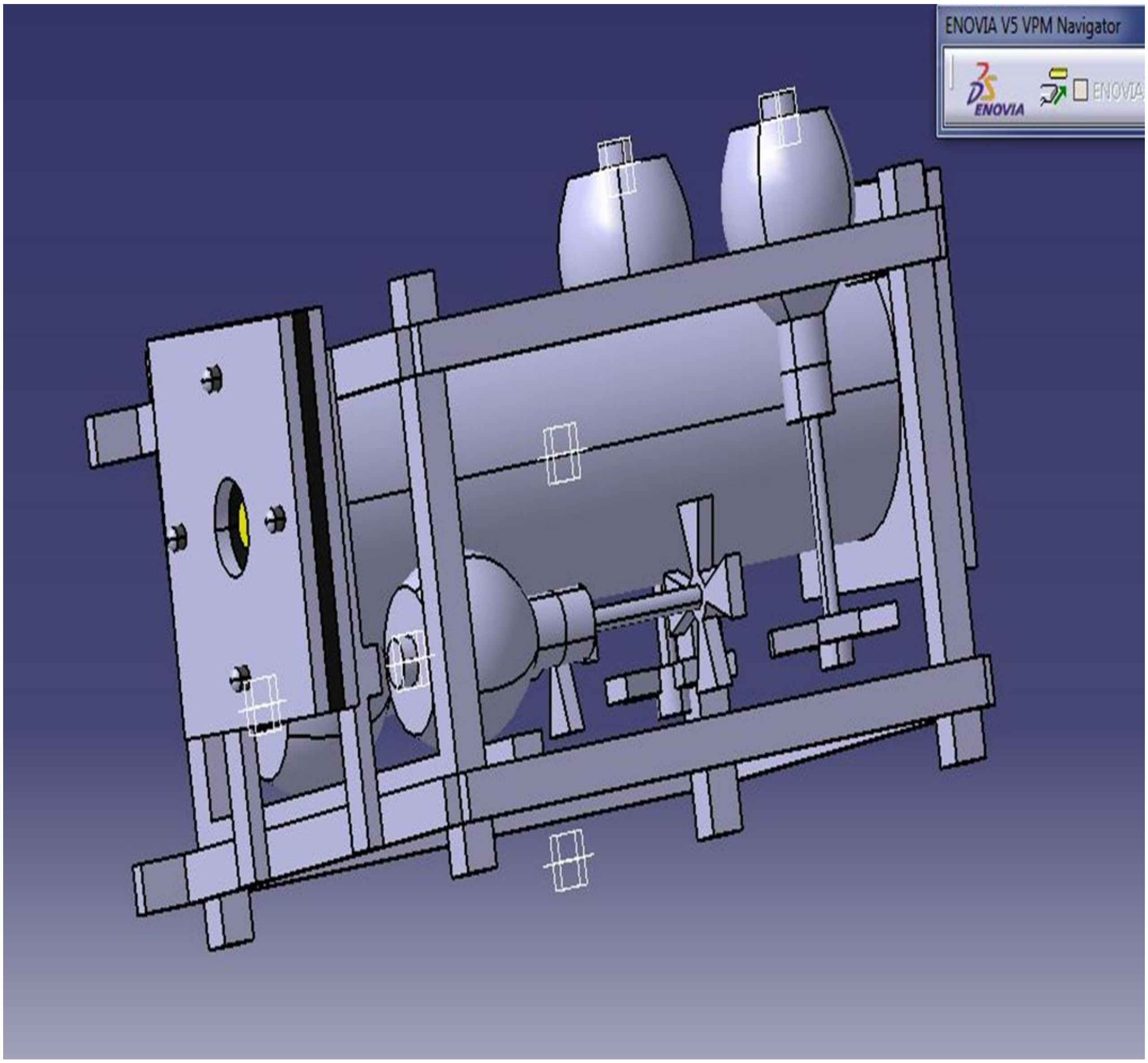

Figure 6.1: CAD model of the underwater robot made in the lab

The defuzzification has been like- If the front obstacle distance is 39.6 and the left obstacle distance is 34.9 and the Right obstacle distance is 60.4 and the Heading angle azimuth angle is 44.4 and Heading angle elevation angle is 12.5 and Target angle Azimuth angle is -29.6 and Target angle EA is 18.1 then the output of motor 1 has speed 1.18, output of motor 2 has speed 0.59, output of motor 3 has speed 0.285 and output of motor 4 has speed 0.286. The results of the FLC are:-

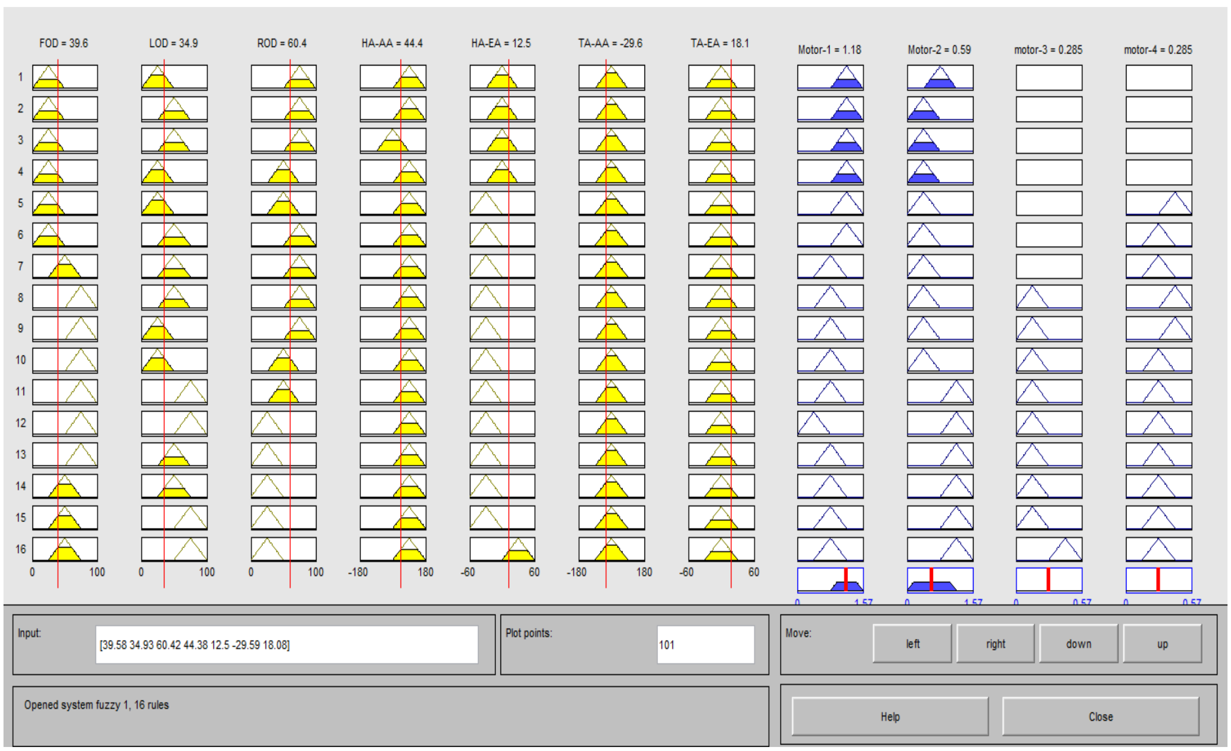

Figure 6.2: Defuzzification values

7. CONCLUSION

An underwater robot has been fabricated with the following parts and their measured length and weights as given in Table 7.1.

Part	Specifications
Acrylic Sheet	110 mm
Rubber Pads Width Side Length	 7 mm 110 mm
Hull length	90 cm
Weight of Robot	8 kg (approx.)
Hull Material	PVC
Supporting Frame	Aluminium
Motor	DC Starting motor With high torque and RPM of 5000 rpm

Table 7.1: Specifications of robot

The robot was tested in water at a depth of 2 meter for obstacle avoidance using Fuzzy Logic controller. The control was perfectly incorporated in hardware. Hence the fuzzy rule base is perfect as it is able to steer the robot avoiding sharp obstacles.

8. REFERENCES

[1]. Roberto Cristi, Fotis A. Papoulias, and Anthony J. Healey, "Adaptive Sliding Mode Control of Autonomous Underwater Vehicles in the Dive Plane," IEEE Journal of Oceanic Engineering, pp.152-160, vol. 15, no.3, July,1990.

[2]. C. Silvestre, A. Pascoal ,"Depth control of the INFANTE AUV using gain-scheduled reduced order output feedback," Control Engineering Practice 15 , pp.883–895,2007 [3]. Ji-Hong Li, Pan-Mook Lee, "Design of an adaptive nonlinear controller for depth control of an autonomous underwater vehicle, “Ocean Engineering 32 , pp.2165–2181, 2005

[4]. Ji Hong Li, Pan Mook Lee, “A neural network adaptive controller design for free-pitch-angle diving behavior of an autonomous underwater vehicle,” Robotics and Autonomous Systems 52 pp.132–147,2005 .

[5]. Xiaocheng, Shi, Jiajia Zhou, Xinqian Bian, Juan Li", Fuzzy Sliding-Mode Controller for the Motion of Autonomous Underwater Vehicle," Proceedings of IEEE International Conference on Mechatronics and Automation, pp.466-470, 2008.

[6]. Yuesheng Luo,Xiuping Wen,Xingyan Zhang,Lirong Fu,Junwei Wang,"The diving depth asymptotic stability control of AUV with control constraint ,"Proceedings of the 8th World Congress on Intelligent Control and Automation July 6-9,China, pp.3461-3465,2010

[7]. Hejia Pan and Ming Xin, "Depth control of autonomous underwater vehicles using indirect robust control method," American Control Conference Fairmont Queen Elizabeth, Montréal, Canada , june 27-29, ,pp.6216-6221,2012

[8]. Woo Jun, Do Wan Kim1, and Ho Jae Lee,"Design of T-S Fuzzy-Model-Based Controller for Depth Control of Autonomous Underwater Vehicles with Parametric Uncertainties," 11th International Conference on Control, Automation and Systems Oct.26-29, 1 in KINTEX, Gyeonggi-do, Korea,pp.1682-1684,2011

[9]. Mugdha S. Naik, Sahjendra N. Singh,"State-dependent Riccati equation-based robust dive plane control of AUV with control constraints,"Ocean Engineering 34, pp.1711–1723, 2007.

[10]. Yoerger, D.R., Slotine, J.E., " Robust trajectory control of underwater vehicles," IEEE Journal of Oceanic Engineering 10 (4),pp. 462–470,1985

[11]. Healey, A.J., Lienard, D., " Multi-variable sliding mode control for autonomous diving and steering of unmanned underwater vehicles," IEEE Journal of Oceanic Engineering 18 (3), pp.327– 338,1993

[12]. Li, J., Lee, P., " Design of an adaptive nonlinear controller for depth control of an autonomous underwater vehicle,". Ocean Engineering, vol. 32, pp.2165–2181,2005

[13]. K.D. Doa,J. Pana and Z.P. Jiang, , "Robust and adaptive path following for underactuated autonomous underwater vehicles. Ocean Engineering 31, pp.1967–1997, 2004

[14]. Narasimhan, M., Singh, S.N., "Adaptive optimal control of an autonomous underwater vehicle in the dive plane using dorsal fins," Ocean Engineering 33 (3–4), 404–416,2006

[15]. Narasimhan, M., Singh, S. "Adaptive input–output feedback linearizing yaw plane control of BAUV using dorsal fins". Ocean Engineering 33 (11–12), 1413–1430, 2006

[16]. R. K. Lea , R. Allen and S. L.Merry, “ A comparative study of control techniques for an underwater flight vehicle,” International Journal of Systems Science, volume 30, number 9, pp. 947- 964, 1999.

[17]. K. P. Venugopal, R. Sudhakar, and A. S. Pandya, “On-Line Learning Control of Autonomous Underwater Vehicles Using Feed forward Neural Networks,” IEEE Journal Of Oceanic Engineering, vol. 17, no. 4, 1992.

[18]. T.Fossen, “Modeling of Marine Vessels'" in Marine Control Systems Guidance, Navigation and Control of Ships, Rigs and Underwater Vehicles, Ed. New York: John Wiley, pp.5- 48, 1999.

[19]. T.Fossen, "Modeling of Marine Vehicles,” in Guidance and control of ocean vehicles, Ed. New York: Wiley, pp.6-55, 1994.